

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Reissue Application of)	Attorney Docket No.: 3600.100
DAVID A. SPEAR ET AL.)	Examiner: Mark Sgantzios
Appln. No.: Not yet assigned)	Group Art Unit: 3401
Filed: Herewith)	
For: SWEPT TURBOMACHINERY)	Application to reissue
BLADE)	U.S. Patent No. 5,642,985

Assistant Commissioner for Patents
Box Patent Application
Washington, D.C. 20231

ASSIGNEE'S STATEMENT
UNDER 37 C.F.R. § 3.73(b)

Sir:

The undersigned, as representative of UNITED TECHNOLOGIES CORPORATION, certifies that, to the best of my knowledge and belief, title to United States Letters Patent No. 5,642,985 is in UNITED TECHNOLOGIES CORPORATION. This title is evidenced by an assignment recorded in the U.S. Patent and Trademark Office on November 17, 1995, at Reel 7772, Frame 0767.

UNITED TECHNOLOGIES CORPORATION

Date: 6/30/99

By:

John Swiatocha
John Swiatocha
Assistant Secretary

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Karen Malatesta
KAREN MALATESTA

*entire interest
indicated in
assignment
10/1/99*

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660E90"9E/EHE60

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Assistant Commissioner for Patents
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Washington, D.C. 20231

ASSENT OF ASSIGNEE TO
REISSUE UNDER 37 C.F.R. § 1.172

Sir:

The undersigned assignee of the entire interest in United States Letters
Patent No. 5,642,985 hereby assents to the above-identified application to reissue
such Letters Patent.

UNITED TECHNOLOGIES CORPORATION

Date: 6/30/99

By: John Swiatocha
John Swiatocha
Assistant Secretary

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Karen Malatesta
KAREN MALATESTA

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Attorney Docket No.: 3600.100

DAVID A. SPEAR ET AL.)

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For: SWEPT TURBOMACHINERY)
BLADE)

Application to reissue
U.S. Patent No. 5,642,985

Assistant Commissioner for Patents
Box Patent Application
Washington, D.C. 20231

OFFER TO SURRENDER LETTERS PATENT

Sir:

The undersigned applicants for the above-identified application for the reissue of Letters Patent No. 5,642,985, for an invention of a SWEPT TURBOMACHINERY BLADE, granted to them on July 1, 1997, the sole owner of which is UNITED TECHNOLOGIES CORPORATION, hereby offer to surrender said Letters Patent.

Date:

6/30/99

Dennis N. Kantor
Executor of the Estate of
David A. Spear, Deceased

Date:

6/28/99

Bruce P. Biederman

Date:

6-25-99

John A. Orosa
John A. Orosa

"Express Mail" mailing label number

EH 328767 816 VS

Date of Deposit June 30, 1999

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Karen Malatesta

KAREN MALATESTA

660E90" 9E/E+EE60
660E90" 9E/E+EE60

Court of Probate, District of Manchester
District Number 077

95-0620

Estate of: Spear, David A.
aka David Alan Spear

Date of Certificate: 06/24/1999

Fiduciary's name and address:

Dennis N. Kantor, Box 280748, 330 Roberts Street, East Hartford, CT
06128-0748
Position of trust: Executor
Date of appointment: 11/28/1995

The undersigned hereby certifies that the fiduciary of the above estate has accepted appointment; executed probate bond according to law or has been excused by will or by statute; and is legally authorized and qualified to act as such fiduciary on said estate; said appointment being unrevoked and in full force as of the above date of certificate.

IN TESTIMONY WHEREOF, I have hereunto set my hand and affixed the seal of this court on the above date of certificate.

COURT SEAL

Mary C McNamara
Mary C. McNamara Judge/Ass't. Clerk

NOT VALID WITHOUT COURT OF PROBATE SEAL IMPRESSED

As used in this document, the word fiduciary includes the plural, where the context so requires.

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Karen Malatesta
KAREN MALATESTA

AIR

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

06/30/99
Jc680 U.S. PTO

Jc511 U.S. PTO
09/343736
06/30/99

In re Reissue Application of)
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Date: June 30, 1999
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KAREN MALATESTA

Assistant Commissioner for Patents
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LETTER ACCOMPANYING REISSUE APPLICATION

Sir:

Pursuant to the practice under 37 C.F.R. § 1.53 and M.P.E.P. §§ 601.01, 1410,
enclosed herewith for filing are the following papers constituting an application for
reissue of United States Letters Patent No. 5,642,985, issued July 1, 1997, to David A.
Spear, Bruce P. Biederman and John A. Orosa for SWEPT TURBOMACHINERY
BLADE.

1. Mounted soft copy of the specification and new claims.
2. A copy of the patent drawings.
3. A soft copy of the printed original patent.
4. Proof of Executor's Authority to take action on behalf of David A. Spear,
deceased.
5. Executed Reissue Declaration and Power of Attorney.

6. Assignee's Statement Under 37 C.F.R. § 3.73(b)
7. Assent of Assignee to Reissue Under 37 C.F.R. § 1.172.
8. Offer to Surrender Letters Patent.
9. The filing fee is computed as follows:

- a. Basic Filing Fee..... \$ 760.00
- b. Independent claims in excess of the
number of independent claims in the
original patent (7 X \$78).....\$ 546.00
- c. Claims in excess of twenty and also in
excess of the number of claims in the
original patent (32 X \$18).....\$ 576.00

Total: \$ 1882.00

The Commissioner is hereby authorized to charge the above fee and any additional fees of any nature whatsoever under 37 C.F.R. § 1.16 and § 1.17 that may be required, or to credit any overpayment, to Deposit Account No. 21-0279. A duplicate of this letter is enclosed.

Pursuant to 37 C.F.R. § 1.174, please transfer the drawings from the patent file to the subject reissue application.

All correspondence should be directed to the following address:

David M. Quinlan, P.C.
40 Nassau Street
Princeton, NJ 08542
Tel: 609-921-8660
Fax: 609-921-8651

By

Registration No. 27,955

Case No.	Case Name	Case Type	Case Status	Case Date	Case Time	Case Location	Case Description	Case Notes	Case Comments
1	John Doe	Case 1	Open	2023-01-01	10:00	New York	Case 1 Description	Case 1 Notes	Case 1 Comments
2	Jane Smith	Case 2	Closed	2023-01-02	11:00	Los Angeles	Case 2 Description	Case 2 Notes	Case 2 Comments
3	Bob Johnson	Case 3	Pending	2023-01-03	12:00	Chicago	Case 3 Description	Case 3 Notes	Case 3 Comments
4	Alice Brown	Case 4	Open	2023-01-04	13:00	San Francisco	Case 4 Description	Case 4 Notes	Case 4 Comments
5	Charlie Davis	Case 5	Closed	2023-01-05	14:00	Seattle	Case 5 Description	Case 5 Notes	Case 5 Comments
6	Diana White	Case 6	Pending	2023-01-06	15:00	Portland	Case 6 Description	Case 6 Notes	Case 6 Comments
7	Frank Green	Case 7	Open	2023-01-07	16:00	San Diego	Case 7 Description	Case 7 Notes	Case 7 Comments
8	Grace Black	Case 8	Closed	2023-01-08	17:00	Phoenix	Case 8 Description	Case 8 Notes	Case 8 Comments
9	Henry Blue	Case 9	Pending	2023-01-09	18:00	San Jose	Case 9 Description	Case 9 Notes	Case 9 Comments
10	Ivy Gold	Case 10	Open	2023-01-10	19:00	San Antonio	Case 10 Description	Case 10 Notes	Case 10 Comments
11	Jack Silver	Case 11	Closed	2023-01-11	20:00	San Jose	Case 11 Description	Case 11 Notes	Case 11 Comments
12	Karen Bronze	Case 12	Pending	2023-01-12	21:00	San Jose	Case 12 Description	Case 12 Notes	Case 12 Comments
13	Leo Copper	Case 13	Open	2023-01-13	22:00	San Jose	Case 13 Description	Case 13 Notes	Case 13 Comments
14	Mia Iron	Case 14	Closed	2023-01-14	23:00	San Jose	Case 14 Description	Case 14 Notes	Case 14 Comments
15	Noah Steel	Case 15	Pending	2023-01-15	00:00	San Jose	Case 15 Description	Case 15 Notes	Case 15 Comments
16	Olivia Tin	Case 16	Open	2023-01-16	01:00	San Jose	Case 16 Description	Case 16 Notes	Case 16 Comments
17	Peter Lead	Case 17	Closed	2023-01-17	02:00	San Jose	Case 17 Description	Case 17 Notes	Case 17 Comments
18	Quinn Zinc	Case 18	Pending	2023-01-18	03:00	San Jose	Case 18 Description	Case 18 Notes	Case 18 Comments
19	Rachel Nickel	Case 19	Open	2023-01-19	04:00	San Jose	Case 19 Description	Case 19 Notes	Case 19 Comments
20	Sam Cobalt	Case 20	Closed	2023-01-20	05:00	San Jose	Case 20 Description	Case 20 Notes	Case 20 Comments
21	Tina Manganese	Case 21	Pending	2023-01-21	06:00	San Jose	Case 21 Description	Case 21 Notes	Case 21 Comments
22	Umar Vanadium	Case 22	Open	2023-01-22	07:00	San Jose	Case 22 Description	Case 22 Notes	Case 22 Comments
23	Victoria Chromium	Case 23	Closed	2023-01-23	08:00	San Jose	Case 23 Description	Case 23 Notes	Case 23 Comments
24	Walter Molybdenum	Case 24	Pending	2023-01-24	09:00	San Jose	Case 24 Description	Case 24 Notes	Case 24 Comments
25	Xavier Rhenium	Case 25	Open	2023-01-25	10:00	San Jose	Case 25 Description	Case 25 Notes	Case 25 Comments
26	Yara Ruthenium	Case 26	Closed	2023-01-26	11:00	San Jose	Case 26 Description	Case 26 Notes	Case 26 Comments
27	Zoe Rhodium	Case 27	Pending	2023-01-27	12:00	San Jose	Case 27 Description	Case 27 Notes	Case 27 Comments
28	Adam Palladium	Case 28	Open	2023-01-28	13:00	San Jose	Case 28 Description	Case 28 Notes	Case 28 Comments
29	Bella Silver	Case 29	Closed	2023-01-29	14:00	San Jose	Case 29 Description	Case 29 Notes	Case 29 Comments
30	Carl Gold	Case 30	Pending	2023-01-30	15:00	San Jose	Case 30 Description	Case 30 Notes	Case 30 Comments
31	Dora Copper	Case 31	Open	2023-01-31	16:00	San Jose	Case 31 Description	Case 31 Notes	Case 31 Comments
32	Ethan Iron	Case 32	Closed	2023-02-01	17:00	San Jose	Case 32 Description	Case 32 Notes	Case 32 Comments
33	Fiona Steel	Case 33	Pending	2023-02-02	18:00	San Jose	Case 33 Description	Case 33 Notes	Case 33 Comments
34	George Tin	Case 34	Open	2023-02-03	19:00	San Jose	Case 34 Description	Case 34 Notes	Case 34 Comments
35	Helen Lead	Case 35	Closed	2023-02-04	20:00	San Jose	Case 35 Description	Case 35 Notes	Case 35 Comments
36	Ivan Zinc	Case 36	Pending	2023-02-05	21:00	San Jose	Case 36 Description	Case 36 Notes	Case 36 Comments
37	Jane Nickel	Case 37	Open	2023-02-06	22:00	San Jose	Case 37 Description	Case 37 Notes	Case 37 Comments
38	Karl Cobalt	Case 38							

PATENT APPLICATION SERIAL NO. 09/343736

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

07/21/1999 Pallen 00000002 210279 09343736

01 FC:108 760.00 CH
02 FC:109 546.00 CH
03 FC:110 378.00 CH

09/01/1999 NPATTERS 00000003 210279 09343736

01 FC:104 260.00 CH

A swept turbomachinery blade for use in a cascade of such blades is disclosed. The blade (12) has an airfoil (22) uniquely swept so that an endwall shock (64) of limited radial extent and a passage shock (66) are coincident and a working medium (48) flowing through interblade passages (50) is subjected to a single coincident shock rather than the individual shocks. In one embodiment of the invention the forwardmost extremity of the airfoil defines an inner transition point (40) located at an inner transition radius r_{inner} . The sweep angle of the airfoil is nondecreasing with increasing radius from the inner transition radius to an outer transition radius r_{outer} radially inward of the airfoil tip (26), and is nonincreasing with increasing radius between the outer transition radius and the airfoil tip.

Date of Deposit June 30, 1991

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KAREN MALATESTA

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SWEPT TURBOMACHINERY BLADE

TECHNICAL FIELD

This invention relates to turbomachinery blades, and particularly to blades whose airfoils are swept to minimize the adverse effects of supersonic flow of a working medium over the airfoil surfaces.

BACKGROUND OF THE INVENTION

Gas turbine engines employ cascades of blades to exchange energy with a compressible working medium gas that flows axially through the engine. Each blade in the cascade has an attachment which engages a slot in a rotatable hub so that the blades extend radially outward from the hub. Each blade has a radially extending airfoil, and each airfoil cooperates with the airfoils of the neighboring blades to define a series of interblade flow passages through the cascade. The radially outer boundary of the flow passages is formed by a case which circumscribes the airfoil tips. The radially inner boundary of the passages is formed by abutting platforms which extend circumferentially from each blade.

During engine operation the hub, and therefore the blades attached thereto, rotate about a longitudinally extending rotational axis. The velocity of the working medium relative to the blades increases with increasing radius. Accordingly, it is not uncommon for the airfoil leading edges to be swept forward or swept back to mitigate the adverse aerodynamic effects associated with the compressibility of the working medium at high velocities.

One disadvantage of a swept blade results from pressure waves which extend along the span of each airfoil suction surface and reflect off the surrounding case. Because the airfoil is swept, both the incident waves and the reflected waves are oblique to the case. The reflected waves interact with the incident waves and coalesce into a planar aerodynamic shock which extends across the interblade flow channel between neighboring airfoils. These "endwall shocks" extend radially inward a limited distance from the case. In addition, the compressibility of the working medium causes a passage shock, which is unrelated to the above described endwall shock, to extend across the passage from the leading edge of each blade to the suction surface of the adjacent blade. As a result, the working medium gas flowing into the channels encounters multiple shocks and experiences unrecoverable losses in velocity and total pressure, both of which degrade the engine's efficiency. What is needed is a turbomachinery blade whose airfoil is swept to mitigate the effects of working medium compressibility while also avoiding the adverse influences of multiple shocks.

DISCLOSURE OF THE INVENTION

It is therefore an object of the invention to minimize the aerodynamic losses and efficiency degradation associated with endwall shocks by limiting the number of shocks in each interblade passage.

According to the invention, a blade for a blade cascade has an airfoil which is swept over at least a portion of its span, and the section of the airfoil radially coextensive with the endwall shock intercepts the endwall shock extending from the neighboring airfoil so that the endwall shock and the passage shock are coincident.

In one embodiment the axially forwardmost extremity of the airfoil's leading edge defines an inner transition point located at an inner transition radius radially inward of the

The invention has the advantage of limiting the number of shocks in each interblade passage so that engine efficiency is maximized.

FIG. 1 is a cross sectional side elevation of the fan section of a gas turbine engine showing a swept back fan blade according to the present invention.

FIG. 3 is a developed view taken along the line 3—3 of FIG. 2 illustrating the tips of four blades of the present invention along with four prior art blades shown in phantom.

FIG. 5 is a developed view similar to FIG. 3 illustrating an alternative embodiment of the invention and showing prior art blades in phantom.

FIG. 7 is a developed view taken along the line 7-7 of FIG. 6 illustrating the tips of four blades of the present invention along with four prior art blades shown in phantom.

Referring to FIGS. 1-3, the forward end of a gas turbine engine includes a fan section 10 having a cascade of fan blades 12. Each blade has an attachment 14 for attaching the blade to a disk or hub 16 which is rotatable about a longitudinally extending rotational axis 18. Each blade also has a circumferentially extending platform 20 radially outward of the attachment. When installed in an engine, the platforms of neighboring blades in the cascade abut each other to form the cascade's inner flowpath boundary. An airfoil 22 extending radially outward from each platform has a root 24, a tip 26, a leading edge 28, a trailing edge 30, a pressure surface 32 and a suction surface 34. The axially forwardmost extremity of the leading edge defines an inner transition point 40 at an inner transition radius r_{inner} , radially inward of the tip. The blade cascade is circumscribed by a case 42 which forms the cascade's outer flowpath boundary. The case includes a rubstrip 46 which partially abrades away in the event that a rotating blade contacts the case during engine operation. A working medium fluid such as air 48 is pressurized as it flows axially through interblade passages 50 between neighboring airfoils.

The hub 16 is attached to a shaft 52. During engine
65 operation, a turbine (not shown) rotates the shaft, and
therefore the hub and the blades, about the axis 18 in
direction R. Each blade, therefore, has a leading neighbor

which precedes it and a trailing neighbor which follows it during rotation of the blades about the rotational axis.

The axial velocity V_x (FIG. 3) of the working medium is substantially constant across the radius of the flowpath. However the linear velocity U of a rotating airfoil increases with increasing radius. Accordingly, the relative velocity V_r of the working medium at the airfoil leading edge increases with increasing radius, and at high enough rotational speeds, the airfoil experiences supersonic working medium flow velocities in the vicinity of its tip. Supersonic flow over an airfoil, while beneficial for maximizing the pressurization of the working medium, has the undesirable effect of reducing fan efficiency by introducing losses in the working medium's velocity and total pressure. Therefore, it is typical to sweep the airfoil's leading edge over at least a portion of the blade span so that the working medium velocity component in the chordwise direction (perpendicular to the leading edge) is subsonic. Since the relative velocity V_r increases with increasing radius, the sweep angle typically increases with increasing radius as well. As shown in FIG. 4, the sweep angle σ at any arbitrary radius is the acute angle between a line 54 tangent to the leading edge 28 of the airfoil 22 and a plane 56 perpendicular to the relative velocity vector V_r . The sweep angle is measured in plane 58 which contains both the relative velocity vector and the tangent line and is perpendicular to plane 56. In conformance with this definition sweep angles σ_1 and σ_2 , referred to hereinafter and illustrated in FIGS. 2, 3 and 6 are shown as projections of the actual sweep angle onto the plane of the illustrations.

Sweeping the blade leading edge, while useful for minimizing the adverse effects of supersonic working medium velocity, has the undesirable side effect of creating an endwall reflection shock. The flow of the working medium over the blade suction surface generates pressure waves (shown only in FIG. 1) which extend along the span of the blade and reflect off the case. The reflected waves 62 and the incident waves 60 coalesce in the vicinity of the case to form an endwall shock 64 across each interblade passage. The endwall shock extends radially inward a limited distance, d , from the case. As best seen in the prior art (phantom) illustration of FIG. 3, each endwall shock is also oblique to a plane 67 perpendicular to the rotational axis so that the shock extends axially and circumferentially. In principle, an endwall shock can extend across multiple interblade passages and affect the working medium entering those passages. In practice, expansion waves (as illustrated by the representative waves 68) propagate axially forward from each airfoil and weaken the endwall shock from the airfoil's leading neighbor so that each endwall shock usually affects only the passage where the endwall shock originated. In addition, the supersonic character of the flow causes passage shocks 66 to extend across the passages. The passage shocks, which are unrelated to endwall reflections, extend from the leading edge of each blade to the suction surface of the blade's leading neighbor. Thus, the working medium is subjected to the aerodynamic losses of multiple shocks with a corresponding degradation of engine efficiency.

The endwall shock can be eliminated by making the case wall perpendicular to the incident expansion waves so that the incident waves coincide with their reflections. However other design considerations, such as constraints on the flowpath area and limitations on the case construction, may make this option unattractive or unavailable. In circumstances where the endwall shock cannot be eliminated, it is desirable for the endwall shock to coincide with the passage shock since the aerodynamic penalty of coincident shocks is less than that of multiple individual shocks.

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550E90" 2E/4E60

A swept back airfoil according to the present invention has a leading edge 28, a trailing edge 30, a root 24 and a tip 26 located at a tip radius r_{tip} . An inner transition point 40 located at an inner transition radius $r_{i-inner}$ is the axially forwardmost point on the leading edge. The leading edge of the airfoil is swept back by a radially varying first sweep angle σ_1 in an intermediate region 70 of the airfoil (in FIG. 2 plane 56 appears as the line defined by the plane's intersection with the plane of the illustration and in FIG. 3 the tangent line 54 appears as the point where the tangent line penetrates the plane of the Figure). The intermediate region 70 is the region radially bounded by the inner transition radius $r_{i-inner}$ and the outer transition radius $r_{o-outer}$. The first sweep angle, as is customary in the art, is nondecreasing with increasing radius, i.e. the sweep angle increases, or at least does not decrease, with increasing radius.

The beneficial effect of the invention is appreciated primarily by reference to FIG. 3 which compares the invention (and the associated endwall and passage shocks) to a prior art blade (and its associated shocks) shown in phantom. Referring first to the prior art illustration in phantom, the endwall shock 64 originates as a result of the pressure waves 60 (FIG. 1) extending along the suction surface of each blade. Each endwall shock is oblique to a plane 67 perpendicular to the rotational axis, and extends across the interblade passage of origin. The passage shock 66 also extends across the flow passage from the leading edge of a blade to the suction surface of the blade's leading neighbor. The working medium entering the passages is therefore adversely influenced by multiple shocks. By contrast, the nonincreasing character of the second sweep angle of a swept back airfoil 22 according to the invention causes a portion of the airfoil leading edge to be far enough forward (upstream) in the working medium flow that the section of the airfoil radially coextensive with the endwall shock extending from the airfoil's leading neighbor intercepts the endwall shock 64 (the unique sweep of the airfoil does not appreciably affect the location or orientation of the endwall shock; the phantom endwall shock associated with the prior art blade is illustrated slightly upstream of the endwall shock for the airfoil of the invention for illustrative clarity). In addition, the passage shock 66 (which remains attached to the airfoil leading edge and therefore is translated forward along with the leading edge) is brought into coincidence with the endwall shock so that the working medium does not encounter multiple shocks.

The embodiment of FIGS. 2 and 3 illustrates a blade whose leading edge, in comparison to the leading edge of a 65 conventional blade, has been translated axially forward parallel to the rotational axis (the corresponding translation of the trailing edge is an illustrative convenience—the

location of the trailing edge is not embraced by the invention). However the invention contemplates any blade whose airfoil intercepts the endwall shock to bring the passage shock into coincidence with the endwall shock. For example, FIG. 5 illustrates an embodiment where a section of the tip region is displaced circumferentially (relative to the prior art blade) so that the blade intercepts the endwall shock 64 and brings it into coincidence with the passage shock 66. As with the embodiment of FIG. 3, the displaced section extends radially inward far enough to intercept the endwall shock over its entire radial extent and brings it into coincidence with the passage shock 66. This embodiment functions as effectively as the embodiment of FIG. 3 in terms of bringing the passage shock into coincidence with the endwall shock. However it suffers from the disadvantage that the airfoil tip is curled in the direction of rotation R. In the event that the blade tip contacts the rubstrip 46 during engine operation, the curled blade tip will gouge rather than abrade the rubstrip necessitating its replacement. Other alternative embodiments may also suffer from this or other disadvantages.

The invention's beneficial effects also apply to a blade having a forward swept airfoil. Referring to FIG. 6 and 7, a forward swept airfoil 122 according to the present invention has a leading edge 128, a trailing edge 130, a root 124 and a tip 126 located at a tip radius r_{tip} . An inner transition point 140 located at an inner transition radius r_{inner} is the axially aftmost point on the leading edge. The leading edge of the airfoil is swept forward by a radially varying first sweep angle σ_1 in an intermediate region 70 of the airfoil. The intermediate region is radially bounded by the inner transition radius r_{inner} and the outer transition radius r_{outer} .

The first sweep angle $[\tau_1] \sigma_1$ is nondecreasing with increasing

radius, i.e. the sweep angle increases, or at least does not decrease, with increasing radius.

The leading edge 128 of the airfoil is also swept forward by a radially varying second sweep angle σ_2 in a tip region 74 of the airfoil. The tip region is radially bounded by the outer transition radius r_{outer} and the tip radius r_{tip} . The second sweep angle is nonincreasing (decreases, or at least does not increase) with increasing radius. This is in sharp contrast to the prior art airfoil 122' whose sweep angle increases with increasing radius radially outward of the inner transition radius.

In the forward swept embodiment of the invention, as in the swept back embodiment, the nonincreasing sweep angle σ_2 in the tip region 74 causes the endwall shock 64 to be coincident with the passage shock 66 for reducing the aerodynamic losses as discussed previously. This is in contrast to the prior art blade, shown in phantom where the endwall shock and the passage shock are distinct and therefore impose multiple aerodynamic losses on the working medium.

In the swept back embodiment of FIG. 2, the inner transition point is the axially forwardmost point on the leading edge. The leading edge is swept back at radii greater than the inner transition radius. The character of the leading edge sweep inward of the inner transition radius is not embraced by the invention. In the forward swept embodiment of FIG. 6, the inner transition point is the axially aftmost point on the leading edge. The leading edge is swept forward at radii greater than the inner transition radius. As with the swept back embodiment, the character of the leading edge sweep inward of the inner transition radius is not embraced by the invention. In both the forward swept

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and back swept embodiments, the inner transition point is illustrated as being radially outward of the airfoil root. However the invention also comprehends a blade whose inner transition point (axially forwardmost point for the swept back embodiment and axially aftmost point for the forward swept embodiment) is radially coincident with the leading edge of the root. This is shown, for example, by the dotted leading edge 28" of FIG. 2.

The invention has been presented in the context of a fan blade for a gas turbine engine, however, the invention's applicability extends to any turbomachinery airfoil wherein flow passages between neighboring airfoils are subjected to multiple shocks.

We claim:

1. A turbomachinery blade for a turbine engine having a cascade of blades rotatable about a rotational axis so that each blade in the cascade has a leading neighbor and a trailing neighbor, and each blade cooperates with its neighbors to define flow passages for a working medium gas, the blade cascade being circumscribed by a case and under some operational conditions an endwall shock extends a limited distance radially inward from the case and also extends axially and circumferentially across the flow passages, and a passage shock also extends across the flow passages, the turbomachinery blade including an airfoil having a leading edge, a trailing edge, a root, a tip and an inner transition point located at an inner transition radius radially inward of the tip, the blade characterized in that at least a portion of the leading edge radially outward of the inner transition point is swept and a section of the airfoil radially coextensive with the endwall shock extending from the leading neighbor intercepts the endwall shock so that the endwall shock and the passage shock are coincident.

2. A turbomachinery blade for a turbine engine having a cascade of blades rotatable about a rotational axis so that each blade in the cascade has a leading neighbor and a trailing neighbor, and each blade cooperates with its neighbors to define flow passages for a working medium gas, the blade cascade being circumscribed by a case and under some operational conditions an endwall shock extends a limited distance radially inward from the case and also extends axially and circumferentially across the flow passages and a passage shock also extends across the flow passages, the turbomachinery blade including an airfoil having a leading edge, a trailing edge, a root, a tip located at a tip radius, an inner transition point located at an inner transition radius radially inward of the tip, and an outer transition point at an outer transition radius radially intermediate the inner transition radius and the tip radius, the blade having a tip region bounded by the outer transition radius and the tip radius, and an intermediate region bounded by the inner transition radius and the outer transition radius, the blade characterized in that the leading edge is swept in the intermediate region at a first sweep angle which is generally nondecreasing with increasing radius, and the leading edge is swept over at least a portion of the tip region at a second sweep angle which is generally nonincreasing with increasing radius so that the section of the airfoil radially coextensive with the endwall shock extending from the leading neighbor intercepts the endwall shock so that the endwall shock and the passage shock are coincident.

3. The turbomachinery blade of claim 1 or 2 characterized in that the inner transition radius is coincident with the root at the leading edge of the blade.

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the tip region is translated forward to provide a sweep angle that causes the blade to intercept the shock.

6. The turbomachinery blade of claim 5, wherein the sweep angle decreases throughout the tip region.

8. The turbomachinery blade of any one of claims 4 to 7,
wherein an inward boundary of the intermediate region is coincident with a root
end of the blade.

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10. A blade for a gas turbine engine fan comprising a plurality of blades mounted for rotation within a case circumscribing the blades and forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

the blade has a configuration enabling the fan to rotate at speeds providing supersonic flow velocities in at least a portion of each passage;

the blade has a leading edge with an intermediate region and a tip region beginning at an outward boundary of the intermediate region and extending to a tip end of the blade, the intermediate region having a sweep angle that does not decrease from the beginning to the outward boundary of the intermediate region; and

throughout the tip region the sweep angle is less than the sweep angle at the outward boundary of the intermediate region.

11. The blade of claim 10, wherein the intermediate region is swept rearward and the tip region is translated forward.

12. The blade of claim 10, wherein the intermediate region is swept forward and the tip region is translated rearward.

13. The blade of claim 10, wherein the tip region sweep angle decreases throughout the tip region.

14. The blade of claim 13, wherein the intermediate region sweep angle increases throughout the intermediate region.

15. The blade of any one of claims 10 to 14, wherein an inward boundary of the intermediate region is coincident with a root end of the blade.

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16. The blade of claim 10, wherein:

the intermediate region is swept rearward and the tip region is translated forward; and

the leading edge of the blade has an inner region beginning at a root end of the blade and extending to an inward boundary of the intermediate region, the inner region being swept forward.

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17. The blade of claim 16, wherein:

the intermediate region sweep angle increases throughout the intermediate region; and

the tip region sweep angle decreases throughout the tip region.

18. A blade for a gas turbine engine fan comprising a plurality of blades mounted for rotation within a case circumscribing the blades and forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

the blade has a configuration enabling the fan to rotate at speeds providing supersonic flow velocities in at least a portion of each passage;

the blade has a leading edge with an intermediate region and a tip region beginning at an outward boundary of the intermediate region and extending to a tip end of the blade, the intermediate region being swept rearward at a sweep angle that does not decrease from the beginning to the outward boundary of the intermediate region; and

the tip region is translated forward from the outward boundary of the rearwardly swept intermediate region.

19. The blade of claim 18, wherein the tip region maintains a rearward sweep throughout the tip region.

20. Turbomachinery for a gas turbine engine, comprising a plurality of blades mounted for rotation within a case circumscribing the blades and forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

each blade has a configuration enabling the turbomachinery to rotate at speeds providing supersonic working medium gas velocities at least in the vicinity of the passages proximate to the case;

each blade has a leading edge with a swept intermediate region and a swept tip region beginning at an outward boundary of the intermediate region and extending to a tip end of the blade, the intermediate region of each blade having a sweep angle that does not decrease from the beginning to the outward boundary of the intermediate region; and

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throughout the tip region the sweep angle of each blade is less than the sweep angle at the outward boundary of the intermediate region.

21. The turbomachinery of claim 20, wherein the intermediate region of each blade is swept rearward and the tip region is translated forward.

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22. The turbomachinery of claim 21, wherein:

the intermediate region sweep angle of each blade increases throughout the intermediate region; and

the tip region sweep angle of each blade decreases throughout the tip region.

23. The turbomachinery of claim 22, wherein the leading edge of each blade has an inner region beginning at a root end of the blade and extending to an inward boundary of the intermediate region, the inner region being swept forward.

24. The turbomachinery of claim 20, wherein the intermediate region of each blade is swept forward and the tip region is translated rearward.

25. The turbomachinery of claim 24, wherein the tip region sweep angle of each blade decreases throughout the tip region.

26. The turbomachinery of claim 25, wherein the intermediate region sweep angle of each blade increases throughout the intermediate region.

27. A gas turbine engine fan comprising a plurality of identical blades, each blade being mounted for rotation within a case circumscribing the blades and having an inner wall forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

each blade has a configuration enabling the fan to rotate at speeds providing supersonic working medium gas velocities in the vicinity of the passages proximate to the case;

each blade has a leading edge with an inner region, an intermediate region and a tip region, the inner region beginning at a root end of

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the blade and extending to an inward boundary of the intermediate region, and the tip region extending from an outward boundary of the intermediate region to a tip end of the blade; and

the inner region is swept forward, the intermediate region is swept rearward at a sweep angle that does not decrease, and the tip region is translated forward from the outward boundary of the intermediate region.

28. The gas turbine engine fan of claim 27, wherein the tip region maintains a rearward sweep throughout the tip region.

29. The gas turbine engine fan of claim 27, wherein:

the intermediate region sweep angle of each blade increases throughout the intermediate region; and

the tip region of each blade is swept at a sweep angle that decreases throughout the tip region.

30. A blade for a gas turbine engine rotatable within a case at speeds providing supersonic flow over at least a portion of the blade, wherein the blade leading edge has a rear swept middle region ending at a tip region that is translated forward from the end of the middle region.

31. The blade of claim 30, wherein the tip region maintains a rearward sweep throughout the tip region.

32. The blade of claim 30, wherein the leading edge has a forward swept inner region.

33. The blade of claim 32, wherein the sweep angle of the middle region increases throughout the middle region.

34. The blade of claim 33, wherein throughout the tip region the sweep angle is less than the sweep angle at the end of the middle region.

35. The blade of claim 34, wherein the sweep angle of the tip region decreases from the end of the middle region to a tip end of the blade.

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36. A blade for a gas turbine engine rotatable within a case at speeds providing supersonic flow over at least a portion of the blade, wherein the blade leading edge has a forward swept middle region ending at a tip region that is translated rearward from the end of the middle region.

37. The blade of claim 36, wherein the tip region maintains a forward sweep throughout the tip region.

38. The blade of claim 36, wherein the leading edge has a rear swept inner region.

39. The blade of claim 38, wherein the sweep angle of the middle region increases throughout the middle region.

40. The blade of claim 39, wherein throughout the tip region the sweep angle is less than the sweep angle at the end of the middle region.

41. The blade of claim 40, wherein the sweep angle of the tip region decreases from the end of the middle region to a tip end of the blade.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Reissue Application of

DAVID A. SPEAR ET AL.

Appln. No.: Not yet assigned

Filed: Herewith

For: SWEPT TURBOMACHINERY
BLADE

) Attorney Docket No.: 3600.100

) Examiner: Mark Sgantzios

) Group Art Unit: 3401

) Application to reissue
) U.S. Patent No. 5,642,985

Assistant Commissioner for Patents
Box Patent Application
Washington, D.C. 20231

REISSUE DECLARATION AND POWER OF ATTORNEY

Sir:

We, DAVID A. SPEAR, who was a United States citizen residing at

Manchester, Connecticut, at the time of his death on October 22, 1995, BRUCE P.

BIEDERMAN, a United States citizen residing at West Hartford, Connecticut, and

JOHN A. OROSA, a United States citizen residing at Palm Beach Gardens, Florida,

hereby declare and say that:

1. We believe that we are the original, first and joint inventors of the subject matter which is claimed in the subject reissue application and for which a reissue patent is sought on the invention entitled SWEPT TURBOMACHINERY BLADE, the specification of which is filed herewith.

"Express Mail" mailing label number
EL 328767816 US

Date of Deposit June 30 1999

I hereby certify that this paper or fee
is being deposited with the United States
Postal Service "Express Mail Post Office
to Addressee" service under 37 CFR 1.10
on the date indicated above and is addressed

to The Commissioner of Patents and Trade-
marks Washington DC 20231

Karen Malatesta
KAREN MALATESTA

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2. We have reviewed and understand the contents of the reissue application, including the claims.

3. We acknowledge our duty to disclose to the U.S. Patent and Trademark Office all information known to be material to patentability as defined in 37 C.F.R. § 1.56.

4. We believe that the original above-identified U.S. Patent No. 5,642,985 is partly inoperative by reason of us having claimed less than we had the right to claim in that patent. Specifically, we believe that we were entitled to claims to at least the following subject matter:

A turbomachinery blade for a gas turbine engine fan comprising a plurality of blades mounted for rotation about a fan axis with neighboring blades forming passages for a working medium gas, wherein:

the blade has a configuration enabling the fan to rotate at speeds providing supersonic flow velocities in at least a portion of each passage causing the formation of a shock in the gas adjacent an inner wall of a case forming an outer boundary for the working medium gas flowing through the passages;

the blade has a leading edge with an intermediate region and a tip region outward of the intermediate region and extending to a tip end of the blade, the intermediate region being swept rearward at a sweep angle that does not decrease; and

the tip region is translated forward to provide a sweep angle that causes the blade to intercept the shock.

A blade for a gas turbine engine fan comprising a plurality of blades mounted for rotation within a case circumscribing the blades and forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

the blade has a configuration enabling the fan to rotate at speeds providing supersonic flow velocities in at least a portion of each passage;

the blade has a leading edge with an intermediate region and a tip region beginning at an outward boundary of the intermediate region and extending to a tip end of the blade, the intermediate region having a sweep angle that does not decrease from the beginning to the outward boundary of the intermediate region; and

throughout the tip region the sweep angle is less than the sweep angle at the outward boundary of the intermediate region.

A blade for a gas turbine engine fan comprising a plurality of blades mounted for rotation within a case circumscribing the blades and forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

the blade has a configuration enabling the fan to rotate at speeds providing supersonic flow velocities in at least a portion of each passage;

the blade has a leading edge with an intermediate region and a tip region beginning at an outward boundary of the intermediate region and extending to a tip end of the blade, the intermediate region being swept rearward at a sweep angle that does not decrease from the beginning to the outward boundary of the intermediate region; and

the tip region is translated forward from the outward boundary of the rearwardly swept intermediate region.

Turbomachinery for a gas turbine engine, comprising a plurality of blades mounted for rotation within a case circumscribing the blades and forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

each blade has a configuration enabling the turbomachinery to rotate at speeds providing supersonic working medium gas velocities at least in the vicinity of the passages proximate to the case;

each blade has a leading edge with a swept intermediate region and a swept tip region beginning at an outward boundary of the intermediate region and extending to a tip end of the blade, the intermediate region of each blade having a sweep angle that does not decrease from the beginning to the outward boundary of the intermediate region; and

throughout the tip region the sweep angle of each blade is less than the sweep angle at the outward boundary of the intermediate region.

A gas turbine engine fan comprising a plurality of identical blades, each blade being mounted for rotation within a case circumscribing the blades and having an inner wall forming an outer boundary for a working medium gas flowing through passages formed by neighboring blades, wherein:

each blade has a configuration enabling the fan to rotate at speeds providing supersonic working medium gas velocities in the vicinity of the passages proximate to the case;

each blade has a leading edge with an inner region, an intermediate region and a tip region, the inner region beginning at a root end of the blade and extending to an inward boundary of the intermediate region, and the tip region extending from an outward boundary of the intermediate region to a tip end of the blade; and

the inner region is swept forward, the intermediate region is swept rearward at a sweep angle that does not decrease, and the tip region is translated forward from the outward boundary of the intermediate region.

A blade for a gas turbine engine rotatable within a case at speeds providing supersonic flow over at least a portion of the blade, wherein the blade leading edge has a rear swept middle region ending at a tip region that is translated forward from the end of the middle region.

A blade for a gas turbine engine rotatable within a case at speeds providing supersonic flow over at least a portion of the blade, wherein the blade leading edge has a forward swept middle region ending at a tip region that is translated rearward from the end of the middle region.

5. All errors being corrected in the subject reissue application up to the time of filing this declaration, including the error identified above, arose without deceptive intent on our parts.

6. We hereby appoint John Swiatocha, Registration No. 27,955, Kenneth C. Baran, Registration No. 32682, and David M. Quinlan, Registration No. 26,641, as our attorneys to transact all business in the Patent and Trademark Office.

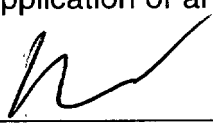
7. All correspondence in the above-identified application should be sent

to:

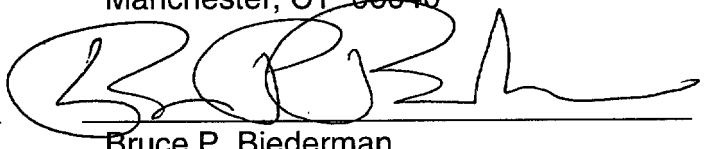
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Each of us hereby declares that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that the statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title XVIII of United States Code, and that such willful false statements may jeopardize the validity of this application or any patent issued thereon.

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Date: 6/30/99


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